

Tests of Light Transmission through PVC extrusions

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I have performed some measurements of light transmission through a PVC cell containing liquid scintillator and wavelength shifting (WLS) fiber with a PMT and APD detector. The results are presented here.

The light transmission of PVC has been measured using a cell of a 48ft. 4.1cm X 2.2cm ID extrusion from Plastic Extrusion Technology (PET). The cell had a loop of 0.8mm Kuraray Y-11 200ppm WLS fiber installed. The entire length of the tube was wrapped in 6mil black plastic garbage bags. A small opening measuring 2cm X 4cm was cut into the bag and masked off with black electrical tape.

The light transmission was measured by coupling the end of the fiber in the cell to a calibrated Quanticon PMT, for high sensitivity, and also to a NovA standard APD running at a gain of 100.

The light transmission was measured under several conditions: darkness, ambient light, and intense light. The ambient light was supplied by the overhead lighting in the University of Minnesota MINOS Module lab, using Phillips Alto F32T8/TL841, a 32W 4100K color temperature light, 2m above the cell. To provide the intense light, a fluorescent lamp was used, a 6400K color temperature 13W bulb made by Regent, and available at your local Menards. This lamp, known as the “Leon Light” in MINOS was specially chosen for finding leaks in the MINOS modules due to its awful (to this human’s eyes) blue light emitted. The response of the fiber to this light is much greater than any other lamp tested. Many lamps tested showed almost measurable signal, due to their reddish output. (Maybe we should just light the whole area with red LEDs.)

The additional layers of PVC were cut from the outer skin of other extrusions from PET. The first additional layer had an exposed area half that of the initial hole, 4cm².

Results:

PMT tests.

Condition	Current	Light-Dark
Dark (2x4cm hole covered)	0.12 μ A	0 μ A
Ambient light	20.0 μ A	19.9 μ A
Intense light	1030 μ A	1030 μ A
Intense light +1.5mm PVC	0.5 μ A	0.4 μ A
Intense light +3.0mm PVC	0.12 μ A	0 μ A

The PMT has a gain of 10pC/pe. Therefore a current of 1uA corresponds to 10⁵pe/s leakage for a detector with PMT quantum efficiency. The leakage of ~20 μ A for

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ambient light translates to 2MHz of photoelectrons in 8cm^2 , and the intense light of 100MHz.

The attenuation of the extra layer of 1.5mm PVC is simply $1030/(0.4*2)=1250$, which gives a light attenuation length in the PVC of 0.2mm.

APD tests

Condition	Current	Light-Dark
Dark (2x4cm hole covered)	1.0 nA	0 nA
Ambient	1.4 na	0.4 nA
Intense light	17.4 nA	16.4 nA
Intense light +1.5mm PVC	1.0 nA	0 nA

The APD has a gain of 100e/pe, so a current of 1nA is a photocurrent of $6E7\text{pe/s}$. The ambient light value is a leakage of 20MHz, and the intense light value corresponds to 1GHz of leakage in the 8cm^2 area. Comparing this to the PMT value of 100MHz is simple. If you use the approximate QE ratio of 10, they are completely consistent.

The light reduction that is needed is to make the light due to the leakage small relative to the dark current in the APD. A typical APD pixel has a dark current of about 60pA at $M=100$. This is 10pA of photocurrent, or 4MHz of single pe signals. If we assume that the exposed area of a typical cell is $2*4\text{cm}*15\text{cm}$. (I pessimistically assume there will be bad gluing, or leakage along the edge). This is 120cm^2 , and would induce a 300MHz leak signal. If we want to attenuate it to a level of 0.1MHz, we would need about 8 attenuation lengths, or 1.6mm thicker PVC, to bring the total to 3.1mm.

It is actually somewhat worse than this, since the measurement here was done 2m into the module, there is extra fiber attenuation, so we don't see the full effect of the leak in this test. Therefore we would probably want to go one or 2 extra PVC attenuation lengths, up to 3.3 or 3.5mm.

Along the edge of the outside modules, the problem is most extreme, since the module is 15m long, assuming an average attenuation factor from the WLS fiber of about 3, this corresponds to an exposure of $6\text{cm}*1500\text{cm}/3=3000\text{cm}^2$. That would create a leak rate of 7500MHz, requiring 11 attenuation lengths (2.2mm), a total thickness of 3.5mm, or about 20 attenuation lengths to reduce it to 0.1MHz.

Additional Tests with PET-B extrusions

An additional round of testing was performed with PET-B extrusions to measure the attenuation length. The test was performed by measuring the current in the same PMT used previously. The fiber and scintillator was inside a PET-Prime extrusion with the additional layer of plastic. The bare sample was in the bare $2\text{cm}*4\text{cm}$ hole to measure the baseline with no attenuation. The samples labeled B are from a PET-B extrusion, samples 1 and 2 are from the outer faces, while samples 3 and 4 are from the inside web.

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Sample A is from a PET-Prime extrusion. The thicknesses were measured with a micrometer.

Sample	thickness(mm)	Dark Current (uA)	Light Current (uA)	Light-Dark in 4cm ²	Attenuation factor	Attenuation length (mm)
bare	0	0.08	1400	699.96		
A1	1.3462	0.08	0.16	0.08	8749.5	0.148313
B1	1.3716	0.08	0.28	0.2	3499.8	0.168079
B2	1.6002	0.08	0.12	0.04	17499	0.163789
B3	1.3462	0.08	0.2	0.12	5833	0.155248
B4	1.27	0.08	0.23	0.15	4666.4	0.150329

The PET-B extrusion samples show a slightly longer attenuation length than the PET-Prime. In the previous tests of the PET-Prime sample the attenuation length was measured to be longer, 0.18mm. The measured attenuation lengths are 0.15 and 0.17. Using the longer attenuation length as a conservative estimate for the attenuation length we would need about 20 attenuation lengths to achieve sufficient opacity. This would be 3 to 3.4mm. The verticals would probably be thick enough, but the horizontal modules at 3mm are unlikely to be thick enough to not need additional light blocking measures.

Conclusions

It appears that the amount of light that leaks through the existing extrusion would make it impossible to operate the detector without additional coverage of some sort. It also appears that increasing the thickness to 3.0mm and 4.5mm would only be sufficient for the 4.5mm thick extrusions. Variations in thickness may also cause problems since it is an exponential attenuation, a slightly thin spot will yield a large light leak.

Light Source Sensitivity

Warning, qualitative results presented below, please forgive the ludicrous precision of the numbers.

I also tested several different light sources for their effectiveness for finding light leaks and to compare to light levels. The standard screw base devices were tested in a reflective trouble-light type housing (60W incand, 26W CF, 75 incand blacklight). These and the others were measured in contact with the extrusion, or as close as was possible to get it to the opening in the black plastic. The most surprising (at least to me) result was that there was an observable response to a RED laser pointer and a red LED.

Lamp	Dark	light	light-dark	rel
Leon (13W fluorescent 6200K color temp)	0.08	1400	1399.92	93.82841823
fluor tube in contact	0.08	432	431.92	28.94906166
60W incandescent	0.08	400	399.92	26.80428954
Blue LED 50ma	0.05	200	199.95	13.40147453
26W CF	0.08	195	194.92	13.06434316
Blue LED 25ma	0.05	100	99.95	6.699061662
Flashlight (2D)	0.08	70	69.92	4.686327078
60W bug-light	0.05	64	63.95	4.286193029
AA Maglight	0.05	35.5	35.45	2.376005362
fluor tube 4100K color temp @2m	0.08	15	14.92	1
indirect sun	0.08	10.8	10.72	0.71849866
75W incandescent black-light	0.05	6	5.95	0.398793566
red laser2 (new)	0.05	2.2	2.15	0.144101877
weak sun	0.08	1.1	1.02	0.068364611
red laser1 (old)	0.08	0.5	0.42	0.028150134
Green LED 75ma	0.05	0.42	0.37	0.024798928
Green LED 50ma	0.05	0.4	0.35	0.023458445
Green LED 25ma	0.05	0.25	0.2	0.013404826
Red LED 50ma	0.05	0.22	0.17	0.011394102
Red LED 80ma	0.05	0.2	0.15	0.010053619
redled25ma	0.05	0.16	0.11	0.007372654
4W UV lamp 254nm	0.05	0.11	0.06	0.004021448
4W UV lamp 365nm	0.05	0.11	0.06	0.004021448

The above results are not adjusted for radiant power that hits the extrusion. This could be done, but may not be necessary.

- Other notable features:
 - LED light output appears to saturate.
 - Response to blue appears dominant.
 - Response to UV appears to be very small.